

STRUCTURE OF A MULTI-INPUT MULTI-OUTPUT MULTICARRIER CODE  
DIVISION MULTIPLE ACCESS COMMUNICATION SYSTEM AND  
COMMUNICATION METHOD THEREOF

**5 Background of Invention**

**1. Field of the Invention**

The invention relates to a structure of a multi-input  
10 multi-output multicarrier code division multiple access  
(MIMO MC-CDMA) communication system and a communication  
method thereof, and more particularly, to a structure of  
a MIMO MC-CDMA communication system and a communication  
method using the space time block encoding technology and  
15 the space-path spreading codes.

**2. Description of the Prior Art**

Application of the network and communication system  
20 is changed from transferring text and audio data to  
transferring multimedia data, so the requirement of  
wireless bandwidth is getting more imperative. The  
multicarrier code division multiple access (MC-CDMA)  
communication system is a method to apply the spreading

technology onto the OFDM structure. The MC-CDMA allows the spreading code to be independently modified on the carrier wave by user to decline and flatten the channel, and provides the benefit of various frequencies to against  
5 interference by using the first-order equalizer.

In the field of the wireless communication system, one of the most important topics is how to eliminate the decay and interference of signals, and a multi-input  
10 multi-output (MIMO) technology is disclosed recently. Pluralities of antennas are installed at both terminals of the wireless transmission, so the spectrum efficiency and transmission reliability can be obviously improved, and the diversity gain can be provided. In 1998, the BLAST  
15 (Bell Laboratories layered space-time) which is an structure of MIMO is disclosed by Foschini et al. (*Wireless Personal Commun.*, vol.6, pg.315-335). The spatial multiplexing function in the point-to-point narrow-band communication can be achieved with this  
20 technology without increasing transmitting power and system bandwidth. The spatial multiplexing function can transmit different data streams at pluralities of antennas simultaneously with the independent and parallel spatial channels, and get more effective spectrum of the

communication system.

On the other hand, for improving the chain quality of the MIMO communication system, the transmit diversity and the receive diversity can be selected to obtain a flattened environment. For example, the space-time coding (STC) technology is a popular one used in the MIMO communication system. However, the spectrum efficiency and diversity cannot be simultaneously optimized, and can only choose one. For solving this problem, the multi-code transmission technology is developed, such as the space-time spreading BLAST (STS BLAST) technology. The technology disclosed by Huang et al. in the IEEE journal is one kind of the multi-code transmission technology (*IEEE Trans. Wireless Commun.*, 2002 vol.1, no.3, pg. 383-392). However, when comparing with the method that only uses the BLAST technology or the space-time block coding (STBC) technology, the multi-code transmission technology can only get the lower spectrum efficiency and diversity gain. When applying to the wide-band system, or named the multiple path environment, the multi-code transmission efficiency will be lowered by the Intersymbol Interference (ISI) and the non-perpendicular substreams, and the conventional technologies cannot have

a better diversity or spectrum efficiency.

### **Summary of Invention**

5       It is therefore a primary objective of the claimed invention to provide a multi-input multi-output multicarrier code division multiple access (MIMO MC-CDMA) communication system and a communication method thereof to provide a great spectrum efficiency and chain quality.

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      It is therefore another objective of the claimed invention to provide a MIMO MC-CDMA communication system that can accomplish great spectrum efficiency and chain quality simultaneously.

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      It is therefore a further objective of the claimed invention to provide a MIMO MC-CDMA communication system and a communication method thereof using the space time block encoding technology and the space-path spreading  
20 codes to obtain a great spectrum efficiency and chain quality.

      According to the claimed invention, a structure of a MIMO MC-CDMA communication system is disclosed. The

transmitter comprises: a de-multiplexer for receiving a user's data and outputting the data divided into a plurality of parallel data streams; a plurality of space time block encoders individually receiving the parallel data streams of the de-multiplexer and outputting the data streams after encoding; a plurality of space-path spreaders receiving outputted data from the space time block encoders and outputting received data after spreading with a pre-designed space-path spreading code; and a plurality of transmit antennas, each transmit antenna receives outputted data from each space-path spreader and transmitting received data through multiple paths.

The present invention also discloses a receiver applied on the above-mentioned MIMO MC-CDMA communication system. The receiver comprises: a plurality of receive antennas for receiving data transmitted by the transmit antennas; a plurality of matched filters individually receiving data received by the receive antennas and despreding it in accordance with the space-path spreading code; a space-time linear combiner receiving data despread by the matched filters and outputting received data after combining; a BLAST detector receiving

data outputted by the space-time linear combiner, separating mutually interfering signal from the multiple transmit antennas, obtaining diversity gain, and outputting operated data; and a multiplexer receiving  
5 data outputted by the BLAST detector and outputting data after multiplexing.

The present invention further discloses a MIMO MC-CDMA communication method. The step of transmitting data  
10 comprises: simultaneously transferring a transmitting data to a plurality of parallel data streams; space time block encoding each parallel data stream; spreading the encoded data streams with a pre-designed space-path spreading code; and collecting the spread parallel data  
15 streams, transferring to a plurality of transmit antennas, and transmitting data with the transmit antennas through a multiple paths.

The step of receiving data of the MIMO MC-CDMA  
20 communication method comprises: receiving data transmitted by the transmit antennas through a plurality of receive antennas; despread data received by the receive antennas through a plurality of corresponding matched filters in accordance with the pre-designed

space-path spreading code; combining the despread data with a linear combiner; and separating mutually interfering signal from the combined data with a BLAST detector, and outputting data after multiplexing it with  
5 a multiplexer.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed  
10 description of the preferred embodiment that is illustrated in the various figures and drawings.

### **Brief Description of Drawings**

15 Fig.1(a) is a schematic diagram of a transmitter of a MC-CDMA system according to the present invention.

Fig.1(b) is a schematic diagram of a receiver of a MC-CDMA system according to the present invention.

Fig.2 is a schematic diagram of another embodiment of  
20 a MC-CDMA system according to the present invention.

Fig.3 is a schematic diagram of a further embodiment of a MC-CDMA system according to the present invention.

10 de-multiplexer

12 space time block encoder  
 14 space-path spreader  
 16 transmit antenna  
 18 receive antenna  
 5 20 matched filter  
 22 space-time linear combiner  
 24 BLAST detector  
 26 multiplexer

## 10 Detailed Description

The claimed structure of a MIMO MC-CDMA communication system is shown in Figs.1(a) and 1(b). Fig.1(a) is a schematic diagram of a transmitter of this system, Fig.1(b) is a schematic diagram of a receiver of this system, and this structure is constructed on the multiple paths of frequency setting. The transmitter of the base station has  $N_t$  transmit antenna 16 providing  $K$  users to transmit data simultaneously. As shown in Fig.1(a), the data streams of each user are processed by a de-multiplexer 20 to produce  $LN_t$  substreams, and the substreams can be divided into  $L$  groups of parallel data streams with  $N_t$  symbols and outputted from the de-multiplexer 10. The data stream of user can be shown as  $d_k(i)$ , wherein  $k=1,2,\dots,K$  means



$K$  users. After processing by the de-multiplexer 10, the substreams can be shown as  $d_{k,p}^{(n_t)}(i) = d_k(N_t(i+p-1)+n_t-1)$ , wherein  $n_t=1,2,\dots,N_t$ ,  $p=1,2,\dots,L$ , and  $L$  is the path length (the unit is chip). The  $L$  groups of parallel data streams outputted  
5 by the de-multiplexer are space-time block coded with the  $L$  space time block coders (STBC) 12, and in the coded  $L$  data streams, the symbol of each data stream has same space time block coding structure. That means that the symbols with the same  $N_t$  are related complex conjugation  
10 multiplying a minus sign. The space time block coding technology can provide various space to diversify and obtain better chain quality.

Then, the coded parallel data streams are individually  
15 passed the space-path spreader 14. The data streams are spread with the pre-designed space-path spreading codes  $\mathbf{t}_{k,p}$  to anticipatively suppress the multiple access interference (MAI) and anticipatively equalize the multiple paths. After spreading, the  $n_{t\text{th}}$  data stream of  
20 each group of the substreams are added and transmitted to the  $n_{t\text{th}}$  antenna. The transmission signal on the  $N_t$  transmit antenna is  $\mathbf{s}(t) = [s^{(1)}(t), s^{(2)}(t), \dots, s^{(N_t)}(t)]^T$ , wherein  $s^{(n_t)}(t) = \sum_{k=1}^K s_{k,i}^{(n_t)}(t)$ . In the MC-CDMA system, the transmission signal  $s_{k,i}^{(n_t)}(t)$  of the  $i_{\text{th}}$  data symbol transmitted by the  $k_{\text{th}}$

user through the  $n_{i\text{th}}$  transmit antenna 16 can be shown as:

$$s_{k,i}^{(n_i)}(t) = \sum_{m=0}^{M-1} \sum_{p=1}^L t_{k,p}(m) d_{k,p}^{(n_i)}(i) \exp\{j2\pi m \frac{t}{T_b}\} \quad (1) \text{ where}$$

rein,  $t \in [iT_b, (i+1)T_b]$ ,  $T_b$  is symbol interval,  $t_{k,p}(m)$  is the  
 5  $(m+1)\text{th}$   $t_{k,p}$ ,  $d_{k,p}^{(n_i)}(i)$  is  $i\text{th}$  data symbol with the average zero  
 and the variation  $P_T/N_t$ ,  $P_T$  is the total transmission  
 energy average. The transmission path has  $L$  separated  
 Rayleigh decay path ( $L \ll M$ ), and for simplifying the  
 analysis, if the path delay spread interval of all users  
 10 are the same, a guard time  $T_G$  can be inserted before  
 transmitting  $s_{k,i}^{(n_i)}(t)$  to reduce the interference between  
 symbols.

For receiving the signals transmitted by the transmit  
 15 antenna 16, assuming user  $q$  is the matched user, the  
 signals received by the  $m_r\text{th}$  receive antenna 18 of the  
 $q\text{th}$  mobile station can be shown as:

$$\bar{x}_q^{(m_r)}(t) = \sum_{k=1}^K \sum_{n_i=1}^{N_t} \sum_{l=1}^L \sum_{i=-\infty}^{\infty} \alpha_{q,l}^{(m_r, n_i)} s_{k,i}^{(n_i)}(t - i(T_b + T_G) - \tau_{q,l} T_c) + \bar{n}_q^{(m_r)}(t) \quad (2)$$

Wherein  $\alpha_{q,l}^{(m_r, n_i)}$  is the decay gain of the  $l\text{th}$  path,  $\tau_{q,l}$  is  
 20 the delay time of the  $n_{i\text{th}}$  transmit antenna 16 of the base  
 station to the  $m_r\text{th}$  receive antenna 18 of the  $q\text{th}$  mobile  
 station,  $\alpha_{q,l}^{(m_r, n_i)}$  is the stable complex Gaussian assuming

average zero,  $T_c = T_b/M$  is the chips interval, and  $\bar{n}_q^{(m_r)}(t)$  is the additional white gauss noise with energy  $\sigma_n^2$ .

After removing the guard time of the received signals,  
 5 when sampling the  $i_{th}$  symbol interval at time  $t = iT_b + nT_c$ ,  
 the produced digital receive data is:

$$\bar{x}_{q,i}^{(m_r)}(n) = \sum_{k=1}^K \sum_{n_l=1}^{N_l} \sum_{l=1}^L \alpha_{q,l}^{(m_r, n_l)} s_{k,i}^{(n_l)}(n - \tau_{q,l}) + \bar{n}_{q,i}^{(m_r)}(n) \quad (3)$$

Wherein  $n = 0, 1, \dots, M-1$ . After the FFT, the receive data in frequency domain is:

$$\begin{aligned} x_{q,i}^{(m_r)}(m) &= FFT\{\bar{x}_{q,i}^{(m_r)}(n)\} \\ 10 \quad &= \sum_{k=1}^K \sum_{n_l=1}^{N_l} \sum_{p=1}^L \sum_{l=1}^L \alpha_{q,l}^{(m_r, n_l)} d_{k,p}^{(n_l)}(i) t_{k,p}(m) \exp\{-j(2\pi \frac{m}{M} \tau_{q,l})\} + n_{q,i}^{(m_r)}(m) \end{aligned} \quad (4)$$

wherein  $m = 0, 1, \dots, M-1$ , and  $n_{q,i}^{(m_r)}(m)$  is the FFT of  $\bar{n}_{q,i}^{(m_r)}(n)$ . For the received data, the  $i_{th}$  symbol data in frequency domain shown in  $M \times 1$  vector is:

$$\begin{aligned} \mathbf{x}_q^{(m_r)}(i) &= [x_{q,i}^{(m_r)}(0), x_{q,i}^{(m_r)}(1), \dots, x_{q,i}^{(m_r)}(M-1)]^T \\ &= \sum_{k=1}^K \sum_{n_l=1}^{N_l} \sum_{p=1}^L \sum_{l=1}^L \alpha_{q,l}^{(m_r, n_l)} d_{k,p}^{(n_l)}(i) \{\mathbf{w}_{q,l} \odot \mathbf{t}_{k,p}\} + \mathbf{n}_q^{(m_r)}(i) \end{aligned} \quad (5)$$

15 wherein,  $\odot$  denotes the Hadamard product,  
 $\mathbf{t}_{k,p} = [t_{k,p}(0), t_{k,p}(1), \dots, t_{k,p}(M-1)]^T$ ,  $\mathbf{n}_q^{(m_r)}(i)$  is the noise vector,  $T$  is the transposed vector, and  $\mathbf{w}_{q,l}$  is the phase shift vector caused by  $\tau_{q,l}$  th the  $l_{th}$  path, whose form is:

$$\mathbf{w}_{q,l} = [1, e^{-j2\pi\tau_{q,l}\frac{1}{M}}, \dots, e^{-j2\pi\tau_{q,l}\frac{(M-1)}{M}}]^T \quad (6)$$

At the receiver, the detection of symbols can be achieved by using the matched filter 20, the space-time linear combiner 22, and the BLAST detector 24, and outputted by the multiplexer 26. Please refer to Fig.1(b), after the receive antenna 18 of the mobile station receives the data signals from the transmitter, the guard time of the received data is removed in advance if the received data has been added the guard time or processed with the inverse fast Fourier transform (IFFT), and reversing the data to the frequency domain with FFT. The transmitter utilizes the space-path spreading codes to suppress the multiple access interference (MAI) and equalize the paths, so the receiver only needs simple matched filter 20 to despread data. The data received by groups of the receive antennas 18 of the receiver is despread by groups of matched filters, and these filters have the space-path spreading codes corresponding to the receiver. The matched filter 20 of the  $q_{th}$  mobile station can be shown in  $\mathbf{c}_q$  with length  $M$ , and the outputting data of the  $m_{r\ th}$  receive antenna 18 of the matched filters 20 corresponding to the mobile station can be shown as:

$$\begin{aligned}
y_q^{(m_r)}(i) &= \mathbf{c}_q^H \mathbf{x}_q^{(m_r)}(i) \\
&= \sum_{k=1}^K \sum_{n_l=1}^{N_l} \sum_{p=1}^L \sum_{l=1}^L \alpha_{q,l}^{(m_r,n_l)} d_{k,p}^{(n_l)}(i) \mathbf{c}_{q,l}^H \mathbf{t}_{k,p} + \tilde{n}_q^{(m_r)}(i)
\end{aligned} \tag{7}$$

wherein  $\mathbf{c}_{q,l} = \mathbf{c}_q \boxtimes \mathbf{w}_{q,l}^*$  is the despreading vector multiplies the phase shift vector of the  $l_{\text{th}}$  path, and  $\tilde{n}_q^{(m_r)}(i) = \mathbf{c}_q^H \mathbf{n}_q^{(m_r)}(i)$  means the noise. The pre-designed space-path spreading codes can effectively suppress the multiple access interference and symbol interference by using the space-path spreading codes to remove the noise, and is shown as:

$$\begin{aligned}
\mathbf{c}_{q,l}^H \mathbf{t}_{k,p} &= 1, & q = k, l = p \\
\mathbf{c}_{q,l}^H \mathbf{t}_{k,p} &= 0, & \text{otherwise}
\end{aligned} \tag{8}$$

wherein  $l=1,2,\dots,L$ ,  $p=1,2,\dots,L$ ,  $k=1,2,\dots,K$ . Solving the equation (8) can obtain:

$$\mathbf{T} = \mathbf{C}(\mathbf{C}^H \mathbf{C})^{-1} \tag{9}$$

$\mathbf{T} = [\mathbf{t}_{1,1}, \dots, \mathbf{t}_{1,L}, \dots, \mathbf{t}_{K,1}, \dots, \mathbf{t}_{K,L}]$  is the space-path spreading codes matrix,  $\mathbf{C} = [\mathbf{C}_1, \mathbf{C}_2, \dots, \mathbf{C}_K]$  is the "phase shift" spreading codes matrix, and  $\mathbf{C}_k = [\mathbf{c}_{k,1}, \mathbf{c}_{k,2}, \dots, \mathbf{c}_{k,L}]$  is the  $M \times L$  codes matrix of the  $k_{\text{th}}$  user which is used to show the valid feature wave in the path delay spreading interval. If  $\mathbf{C}$  has a complete column rank, namely  $M \geq KL$ , the suppressing effect will be greater. When  $M$  is fixed, amount of the valid user is only limited by  $L$ , and the maximum amount of valid user is:

$$K_{\max} = \left\lfloor \frac{M}{L} \right\rfloor \quad (10)$$

For retaining the total transmission energy a fixed value,  $\mathbf{t}_{k,p}$  should be normalized to  $\|\mathbf{t}_{k,p}\|=1$ , that:

$$5 \quad \mathbf{c}_{q,l}^H \mathbf{t}_{k,p} = J_{q,l} \delta[q-k] \delta[l-p] \quad (11)$$

For all  $q, k, l$  and  $p$ ,  $J_{q,l}$  is a normalizing factor.

Substituting the equation (11) into equation (7):

$$y_q^{(m_r)}(i) = \sum_{n_t=1}^{N_t} \sum_{l=1}^L h_{q,l}^{(m_r, n_t)} d_{q,l}^{(n_t)}(i) + \tilde{n}_q^{(m_r)}(i) \quad (12)$$

wherein  $h_{q,l}^{(m_r, n_t)} = \alpha_{q,l}^{(m_r, n_t)} J_{q,l}$  is the effective "compound  
10 channel".

After processing by the matched filter 20, equation (12) can be explained as an equivalent narrow-band MIMO system, which has  $LN_t$  inputs ( $N_t$  continuous symbols) and  
15  $M_r$  outputs (behind the matched filter 20). A flat decay channel inside it has the decay gain  $h_{q,l}^{(m_r, n_t)}$  and the additional noise. A continuous  $N_t$  symbols  $y_q^{(m_r)}(i+n_t-1)$ , whose  $y_{q,n_t}^{(m_r)}(i) = y_q^{(m_r)}(i+n_t-1)$  and  $m_r = 1, 2, \dots, M_r$ ,  $n_t = 1, 2, \dots, N_t$ , is shown in vector form:

$$20 \quad \mathbf{y}_q(i) = [y_{q,1}^{(1)}(i), \dots, y_{q,N_t}^{(1)}(i), y_{q,1}^{(2)}(i), \dots, y_{q,N_t}^{(2)}(i), \dots, y_{q,1}^{(M_r)}(i), \dots, y_{q,N_t}^{(M_r)}(i)]^T \\ = \mathbf{H}_q \mathbf{d}_q(i) + \tilde{\mathbf{n}}_q(i) \quad (13)$$

wherein  $\mathbf{d}_q(i) = [d_{q,1}^{(1)}(i), \dots, d_{q,1}^{(N_t)}(i), \dots, d_{q,L}^{(1)}(i), \dots, d_{q,L}^{(N_t)}(i)]^T$ ,  $\tilde{\mathbf{n}}_q(i)$  is the

noise vector, and the compound channel matrix  $\mathbf{H}_q$  of the  $q_{\text{th}}$  mobile station is:

$$\mathbf{H}_q = \begin{bmatrix} \mathbf{H}_{q,1}^{(1)} & \dots & \mathbf{H}_{q,L}^{(1)} \\ \vdots & \ddots & \vdots \\ \mathbf{H}_{q,1}^{(M_r)} & \dots & \mathbf{H}_{q,L}^{(M_r)} \end{bmatrix} \quad (14)$$

$\mathbf{H}_{q,l}^{(m_r)}$  is the  $N_t \times N_t$  sub matrix of  $\mathbf{H}_q$ ,  $\mathbf{H}_q$  has the complete  
 5 column rank when  $L \leq M_r$ . The BLAST detector 24 can be applied, for example: when  $N_t = 2$

$$\mathbf{H}_{q,l}^{(m_r)} = \begin{bmatrix} h_{q,1}^{(m_r,1)} & h_{q,1}^{(m_r,2)} \\ h_{q,1}^{(m_r,2)} - h_{q,1}^{(m_r,1)} \end{bmatrix} \quad (15)$$

which has a channel structure similar to that of STBC. With the compound channel, a BLAST detector 24 can be used  
 10 in a  $N_t$  symbol cycle to decode  $LN_t$  substreams, and a multiple gain  $L$  is obtained. On the other hand, the transmission diversity gain can be achieved with multiple transmit antenna transmitting the same  $N_t$  symbols.

15 With assistance of linearly combining  $\mathbf{y}_q(i)$  and the compound channel matrix  $\mathbf{H}_q$ , the adequate statistics vector  $\mathbf{z}_q(i)$  with  $LN_t$  dimensions can be obtained as:

$$\mathbf{z}_q(i) = \text{Re}\{\mathbf{H}_q^H \mathbf{y}_q(i)\} = \mathbf{F}_q \mathbf{d}_q(i) + \text{Re}\{\mathbf{H}_q^H \tilde{\mathbf{n}}_q(i)\} \quad (16)$$

wherein  $\mathbf{F}_q = \text{Re}\{\mathbf{H}_q^H \mathbf{H}_q\}$  is a  $LN_t \times LN_t$  matrix, a  $N_t \times N_t$   
 20 diagonal matrix  $\rho_{q,l} \mathbf{I}_{N_t}$  locates on its  $l_{\text{th}}$  diagonal block,  $l = 1, 2, \dots, L$ , and

$$\rho_{q,l} = \sum_{m_r=1}^{M_r} \sum_{n_l=1}^{N_l} |h_{q,l}^{(m_r,n_l)}|^2 \quad (17)$$

shows  $N_t M_r$  total diversity gain ( $N_t$  comes from the transmitter,  $M_r$  comes from the receiver). In view of the equation (16), this system can have  $LN_t$  inputs,  $LN_t$  outputs  
5 and a MIMO flat decay channel. Hence, the  $LN_t$  substreams can be detected by using method of combining MMSE and OSIC when processing the BLAST (please refer to the journal published by Foschini in *IEEE J. Select. Areas Commun*, Nov. 1999, vol. 17, no. 11, page 1841-1852).

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Under the structure of Figs.1(a) and 1(b), the total diversity gain of the MC-CDMA communication system is  $N_t M_r$ , and when  $L \leq M_r$ , the transmission speed is  $L$  (namely multiple gain) and this system can further adjust the  
15 multiple gain and the total diversity gain. Please refer to Fig.2, in this embodiment, the substreams with STBC processed are transmitted to the corresponding space-time spreader with two substreams in one group. When  $L \leq M_r/2$ , the total diversity gain of this system is  $N_t M_r/2$ , and the  
20 transmission speed is  $2L$ . Under the structure of Fig.3, the outputted data of each STBC is transmitted to two space-time spreader. When  $L \leq 2M_r$ , the total diversity gain of this system is  $2N_t M_r$ , and the transmission speed



is  $L/2$ . Similarly, by adjusting the relationship of the STBC and the space-time spreader, the different diversity gains and transmission speeds are obtained. Hence, the MC-CDMA communication system of the present invention can  
5 be suitably selected in space multi-work or variance according to the requirement.

In contrast to the prior art, the present invention discloses a space time block coding technology combined  
10 with the suitable space-path spreading codes, so that the MIMO MC-CDMA communication system can have better ability of space multi-work and space variance to accomplish a greater spectrum efficiency and chain quality. In addition, the spectrum efficiency and the chain quality  
15 can be further adjusted according to actual requirement, and not only improves the system efficiency but also provides various applications.

Those skilled in the art will readily observe that  
20 numerous modifications and alterations of the device may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.